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Effect of packaging atmospheres on storage quality characteristics of heavily marbled beef longissimus steaks

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ABSTRACT

The objective of this study was to investigate the effects of modified atmosphere packaging (MAP) systems on shelf-life and quality of beef steaks with high marbling. Four packaging types were used including 80% O_2 MAP (80% O_2 + 20% CO_2), 50% O_2 MAP (50% O_2 + 30% CO_2 + 20% N_2), carbon monoxide MAP (0.4% CO + 30% CO_2 + 69.6% N_2) and vacuum packaging (VP). Steaks were displayed under simulated retail conditions at 4 °C for 12 days. Purge loss, pH, color stability, oxidative stability and microbial counts were monitored. Aerobically packaged steaks exhibited a bright-red color at the first 4 days. However, discoloration and oxidation became major factors limiting their shelf-life to 8 days. Compared with aerobic packaging, anaerobic packaging extended shelf-life of heavily marbled beef steaks, due to better color stability, together with lower oxidation and microbial populations. Among all packaging methods, CO-MAP had the best preservation for steaks, with more red color than other packaging types.

1. Introduction

Highly marbled fattened cattle, known as snowflake beef in China, are characterized by their ability to deposit a large amount of intramuscular marbling fat. Snowflake beef is widely preferred by consumers in East Asia because of its better palatability than common beef. The price of snowflake beef was usually high in the retail meat markets due to its quite high production costs. In beef production, polyvinyl chloride film (PVC) packaging is generally used for snowflake beef under display. Prolonged exposure to air accelerates discoloration and microbial growth (Lavieri & Williams, 2014), which results in a short shelf-life and severe retail waste. Modified atmosphere packaging (MAP) has been considered an important technology for maintaining quality standards and extending the shelf-life of fresh meat (Esmer, Irkin, Degirmencioglu, & Degirmencioglu, 2011). However, to our knowledge, few have investigated the effects of different MAP on color, oxidative and microbial stability of snowflake beef during distribution and retail display.

Commercially, the gas combination with 80% O_2 and 20% CO_2 is typically used as a high oxygen MAP in promoting fresh beef color (Resconi et al., 2012), which is used in Chinese market for common beef steaks. Nevertheless, MAP with a high concentration of oxygen may cause quality deterioration through lipid and protein oxidation, negatively affecting flavor stability, drip loss and tenderness (Kim, Huff-Lonergan, Sebranek, & Lonergan, 2010). Considering that snowflake beef is rich in fat, the high oxygen MAP may exacerbate these problems. A recent study has found that steaks stored in packages containing 50% oxygen were well accepted compared with other oxygen levels, especially with respect to flavor and texture (Zakrys, Hogan, O'Sullivan, Allen, & Kerry, 2008). Thus one of the objectives is to evaluate whether the quality of snowflake beef can be improved by reducing oxygen levels moderately, without a significant reduction of color stability.

Vacuum packaging (VP) extends the shelf-life of beef even longer than high oxygen MAP because of eliminating oxygen, but the purple color and visible purge loss of meat are unattractive to consumers (Lagerstedt, Ahnström, & Lundström, 2011). Also, carbon monoxide (CO) is sometimes used in MAP for meat systems. Carbon monoxide can result in the formation of carboxymyoglobin, which possesses a very stable, bright-red meat color (Brooks et al., 2008). The US FDA has approved the use of CO in case-ready meats and CO concentration not exceeding 0.4% is generally regarded as safe (FDA, 2004). Previous work reported that MAP with 0.4% CO and VP were the most stable packaging systems for ground beef containing 10–30% fat levels (Lavieri & Williams, 2014). Additionally, Rogers et al. (2014) found CO-MAP reduced lipid oxidation and microbial spoilage of 19% fat ground beef, compared to aerobic packaging. For the quality investigation and applicability of CO-MAP on high-fat meat products, most studies focus on ground meat, whereas the intact high-fat steak is less well researched.

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The objectives of this work were to compare the effects of four different packaging types on the storage quality characteristics of snowflake beef steaks, and determine the most suitable packaging methods.

2. Materials and methods

2.1. Raw materials preparation

The *M. longissimus lumborum* (LL, the anterior 12th rib to the last lumbar vertebrae) were randomly extracted from four fattened steers at a commercial abattoir in Jilin province. Carcasses were conventionally chilled in a chilling room at 2–4 °C for 72 h. Both the left and right loins were obtained, then vacuum packaged, and kept frozen at −20 °C according to the process of production until transported to the laboratory. The fattened cattle were a cross of Bos Japanese Black Cattle and Bos Yanbian Yellow cattle, aged 32 to 37 months old, and raised on the same farm. Carcasses weighted 392 to 423 kg and the rib eye area was 50.1 ± 1.5 cm^2 (mean ± SD), and subcutaneous fat thickness (6–7th rib) was 2.8 ± 0.2 cm (mean ± SD).

2.2. Packaging and storage

Longissimus lumborum muscles were stored at −20 °C for 3 days. Before packaging, samples were thawed at 4 °C for 24 h. Muscles were cut into 2 cm thick steaks and associated external subcutaneous fat was trimmed off. A total of 39 steaks was obtained from both loins of each carcass and mixed, and then randomly packaged in both aerobic packaging types: 80%O_2-MAP (80% O_2 + 20% CO_2), or 50%O_2-MAP (50% O_2 + 30% CO_2 + 20% N_2); or both anaerobic packaging types: CO-MAP (0.4% CO + 30% CO_2 + 69.6% N_2), or vacuum packaging. Three replicates were performed for each treatment at each storage time interval (4, 8, 12 days). Three steaks from each carcass were analyzed for initial data at time zero.

Vacuum packaging was performed on a Multivac C200 (Multivac Sepp Haggenmüller GmbH & Co. KG, Wolfertschwenden, Germany) with 10 mbar vacuum. The vacuum bag (SP21; Sealed Air Corp., Danbury, USA) was 62 μm thick, with the oxygen permeability of 50 cm^3/m^2/24 h at 23 °C, and the water vapor transmission rate of 10 g/m^2/24 h at 38 °C. Steaks in MAP were individually placed in polypropylene trays type TQBC-0775 (oxygen transmission rate: 10 cm^3/m^2/24 h at 23 °C/0% relative humidity, water vapor transmission rate: 15 g/m^2/24 h at 38 °C/90% relative humidity; Sealed Air Corp., Danbury, USA) with Dri-Loc® soak pads (DLS-25; Sealed Air Corp., Danbury, USA). Trays were flushed with the desired gas mixture using a DT-6D packaging machine (Dajiang Machinery Equipment Co., Ltd., Wenzhou, China) and sealed with oxygen-barrier film (oxygen transmission rate: 25 cm^3/m^2/24 h at 23 °C/0% relative humidity, water vapor transmission rate: 10 g/m^2/24 h at 4 °C/100% relative humidity; Lid 1050; Sealed Air Corp., Danbury, USA). O_2, N_2 and CO_2 were mixed using the DT-6D packaging machine. Carbon monoxide MAP was flushed with the targeted atmosphere from a certified gas cylinder prepared by the supplier (Xieli Special Gas Co., Ltd., Jining, China). The modified atmospheres were validated by testing sample packages at the beginning of each treatment with a gas analyzer (PBI-Dansensor A/S; CheckPoint O_2/CO_2, Ringsted, Denmark). The gas headspace to meat ratio was 2:1. All packages were placed in a walk-in cooler (4 ± 1 °C) under fluorescent light (1076 lx; 12 h on per day) to simulate retail conditions. Steaks were removed at 4, 8 and 12 days from packages for microbial and physicochemical analysis.

2.3. Chemical composition analysis

Samples for compositional analysis were obtained from steaks prior to packaging. Analysis (moisture, crude protein, crude fat, and ash content) was conducted according to the methods of 950.46, 981.10, 960.39, 920.153 described by AOAC (1990) respectively.

2.4. pH measurement

pH values of steaks were measured on each analysis day by using a portable pH meter (SenvenGo, Mettler-Toledo, Switzerland). A scissor was used to make a small hole in the center of steaks and an electrode was then inserted. At least three measurements were taken for each steak and averaged.

2.5. Purge loss

Steak weights were recorded at day 0 and each analysis day. Purge loss was determined by measuring the weight loss during storage and calculated as:

$$\%\text{Purge loss} = \frac{(\text{weight on day 0} - \text{weight on day n}) \times 100}{\text{weight on day 0.}}.$$

2.6. Color measurement

The surface color of beef steaks was measured at 0 day (blooming for 30 min exposed to air directly at 4 °C), 4 days, 8 days and 12 days by using an X-Rite spectrophotometer (Model SP62; 8 mm diameter aperture, Illuminant A, 10° observer; X-Rite, Inc., Grand Rapids, USA). At least five scans were taken per steak immediately after opening packages. L^*, a^* and b^* values were recorded, which represent lightness, redness and yellowness, respectively. Hue (h^*) and chroma (C^*) were calculated using the equations: Hue = $arc\ \tan\ (b^*/a^*)$, Chroma = $(a^{*}2 + b^{*}2)^{1/2}$. The instrument measured reflectance between 400 and 700 nm at 10 nm intervals, and Kubelka–Munk K/S ratios were then calculated. The content of metmyoglobin (MetMb) was estimated using the following equation by the ratio K/S 572/525 (AMSA, 2012). Reflectance at specific wavelengths of 525 and 572 nm was calculated through linear interpolation. Samples with 100% of MetMb were created by chemical induction with potassium ferricyanide. Samples with 100% of deoxymyoglobin (DMb) were obtained making a fresh cut surface on the muscle's interior and taking a reflectance measurement immediately after cutting (section IX, B2b).

$$\%\text{MetMb} = \frac{\frac{\text{K/S 572}}{\text{K/S 525}}\text{ for 100\%DMb} - \frac{\text{K/S 572}}{\text{K/S 525}}\text{for sample}}{\frac{\text{K/S 572}}{\text{K/S 525}}\text{for 100\%DMb} - \frac{\text{K/S 572}}{\text{K/S 525}}\text{for 100\%MetMb}} \times 100$$

2.7. Measurement of oxidative stability

2.7.1. Lipid oxidation

Lipid oxidation was assessed by the 2-thiobarbituric acid method of Siu and Draper (1978). Meat samples were taken from multiple locations of each steak in triplicate, and frozen at −80 °C until required analyses within one week. Samples (2.5 g) were homogenized for 2 min in 12.5 ml of distilled water using an Ultra-Turrax T18 homogenizer (T18; IKA, Germany). Subsequently, 10% *(w/v)* trichloroacetic acid was added 12.5 ml and the mixture was vortexed, and then filtered through Whatman No. 1 filter paper. 4 ml of filtrate was added into 1 ml of 0.06 M 2-thiobarbituric acid (TBA) in a 15 ml centrifugal tube. The tubes were incubated in a water bath at 80 °C for 90 min, and the absorbance of the filtrate was measured spectrophotometrically (TU 1901; Purkinje General, Beijing, China) at 532 nm against a blank containing all reagents (2 ml of distilled water, 2 ml of 10% TCA and 1 ml of 0.06 M TBA reagent). Results were expressed as 2-thiobarbituric acid reactive substances (TBARS) in mg malondialdehyde (MDA)/kg beef.